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High resolution landscape change analysis with CORONA KH-4B imagery. A case study from Iron Gates reservoir area

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Abstract

Mapping landscape change at detailed scales is an interesting task when the focus is not only the land cover change. The paper proposes the integration of a diachronic imagery set in a GIS application in order to obtain precise maps of the key qualitative changes along a representative sector of the Danube River Defile where the Iron Gates emerged between 1965-1972 to the border between Romania and Serbia. A photogrammetric process approach was developed for the building of precise historical orthophoto coverage on the basis of a CORONA KH-4B/ DECLASS-1 dataset. This was focused on reconstructing the image geometry and building a precise orientation, together with an aerial triangulation operation. The results were a Digital Surface Model and an orthophoto (about 5 m average geometric accuracy). This data was integrated into a GIS project with vector data extracted from the latest orthophotos (0.5 m, by ANCPI Bucharest) for mapping of landscape changes as an effect of the complex hydrotechnical works. The Iron Gates reservoir level was of about +33 m higher at the beginning of the 1970s in comparison with the primary Danube River level, the road and the railroad moved upslope like Orșova town and other villages. The most dramatic change was related to the total flooding of Ada-Kaleh Island with a Turkish settlement and a Vauban system fortress, an interesting historical and cultural site.

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Keywords: CORONA KH-4B; photogrammetric process; orthophoto; geometric accuracy; GIS mapping; landscape changes.

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1. Introduction

Landscape change analysis is a complex task when the subject of transformation is not usually related to land cover changes [1] or to agricultural land use [2]. KH-4B images, are obtained within the CORONA programme, between 1967 and 1972. They were the first high-resolution satellite imagery, devoted exclusively to military intelligence purposes. Frames were taken using two panoramic cameras, enabling stereoscopic interpretation and generation of photogrammetric products, which recommends them to many current analysis focused on environments. They were previously used for different purposes: archaeological sites analysis [3], climate change modelling [4], urban landscape change mapping [5], land use mapping [6], geomorphology [7].

Romania is one of the countries where industrialization was a main feature of the economy after 1950 [8]. This process had an accelerated rate and put its imprints on the landscapes. One of these changes featured the damming of the Danube River at the Carpathian crossing, where a reservoir of 160-180 km long (upstream to Belgrade) was created after 1965, in a partnership project developed between Romania and Yugoslavia, in order to enhance the navigation conditions and within the Iron Gate I power station. This project needed the flooding of a large area covering the Danube River floodplain and the lower terraces, as the reservoir level increased by 30 m and covered transport infrastructures, towns and villages, including the islands along the main river channel.

The main target is the evaluation of declassified imagery for high resolution lanscape change mapping and analysis within the areas strongly transdormed by anthropogenic activities. For mapping purposes it was necessary to adapt the analysis to high resolution imagery in order to produce accurate vector data and outline the main transformation of landscapes from qualitative point of view. This means that landscape changes featured areas with less than one square kilometre (ex. dam, railroad, road, small villages and town districts, islands on river channel). The main issue was to search for historical data coverage at a suitable resolution (meters), from the 1960s period. Another aspect is that the areas beyond the border are not covered by aerial photos. In this respect, we discovered a possible solution in processing the CORONA KH-4B imagery, obtained by the American spy camera KH-4B for the United States Central Intelligence Agency on film (National Reconnaissance Office Data Book, 1967, declassified 1995). This dataset is provided together with DECLASS-1 imagery on the United States Geological Survey archive with a free access through Earth Explorer website.

2. Study area

The study area is located in Southwestern Romania, along the Danube River and the state border between Romania and Serbia (Fig. 1). It is superposed on the sector of the Danube River Defile, and includes the present-day dam of the Iron Gates reservoir, together with the town of Orșova, where landscape changes were the most complex.

Geographical features are given by steep slopes and features of the narrower valley sectors cut in strong lithology, while small basins and depressions are featured by larger channel sectors superposing on former larger floodplains. Mountain ridges around are lower than 500-700 m, with extended planated sectors [9], [10], some of them belonging to the higher terraces and the former Danube Valley floodplain level. All this landscape was adapted to the new configuration of the Danube River channel after the building of the Iron Gates dam (km 942+950 along the Danube River) with 441 m length and 40 m high, with two power stations of 2100 MW and two locks for navigation purposes on both sides.

The main problem was that this region superposes on the territories of Romania and Serbia, as it is shown in figure 1. This is a difficulty for the generation of the data coverage, because the orthophotos were cut along the border line. For the DECLASS-1 dataset there were no problems because this former classified imagery covered almost all the Eastern Europe.

The main task was the construction of a diachronic image coverage for the same area. The first image coverage is the historical one (August, 1968), that was processed from CORONA KH-4B frames. The latest image was assured by the digital orthophotos of Romania from august-september 2012, produced by ANCPI Bucharest (National Agency for Cadastre and Land Registration) at 0.5 m resolution in Stereographic 1970 projection.

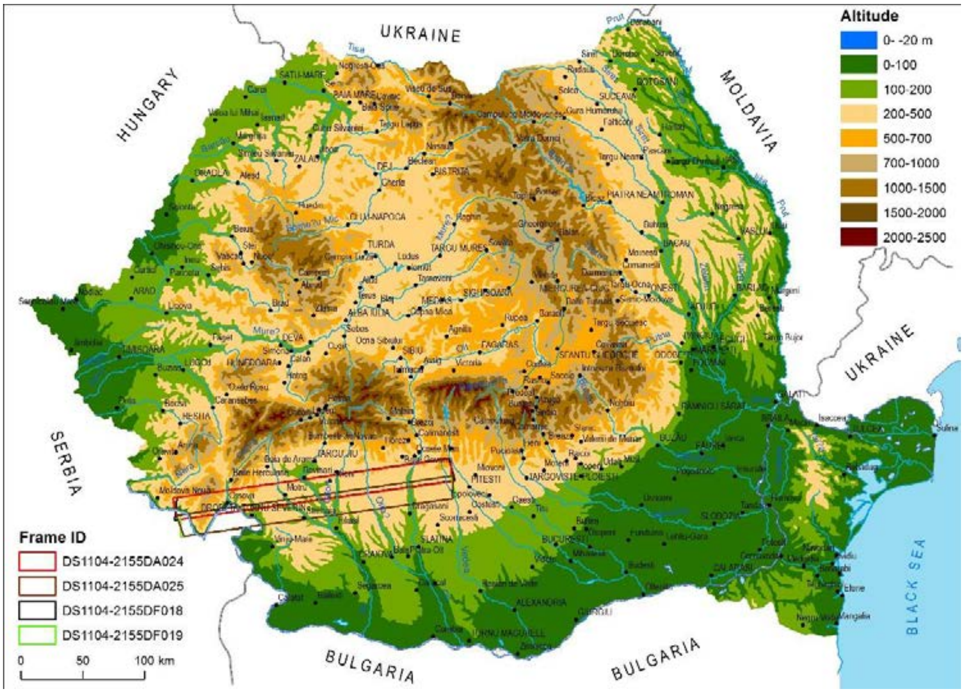

Fig. 1. The study area and the footprint of CORONA KH-4B imagery

3. Materials and methods

The landscape change mapping in the study area at higher resolution need a separate approach, a photogrammetric workflow and a GIS project development for data integration and map production.

3.1. The photogrammetric approach

A photogrammetric approach was necessary in order to recreate accurately a historical moment (August, 1968) that allow the reconstruction the geometric position of the landscape features affected by flooding and the moving to other positions. This typical photogrammetric work is important because a simple geometric correction cannot provide the precise spatial data to be used in landscape change maps.

CORONA KH-4B imagery were previously used by authors for mapping but mainly for photogrammetric purposes [11, 12]. Almost all authors explained the limited accuracy of the derived photogrammetric products and evaluated the precision with the help of control points measured on other recent satellite or aerial high resolution imagery [13], [14], [15].

Our photogrammetric workflow aimed the orthophoto production for August 17, 1968 (Mission ID-1104-2), and needed to follow all the characteristic operations, from data download and visualisation to aerial triangulation, DEM generation and finally orthophoto production (Fig. 2).

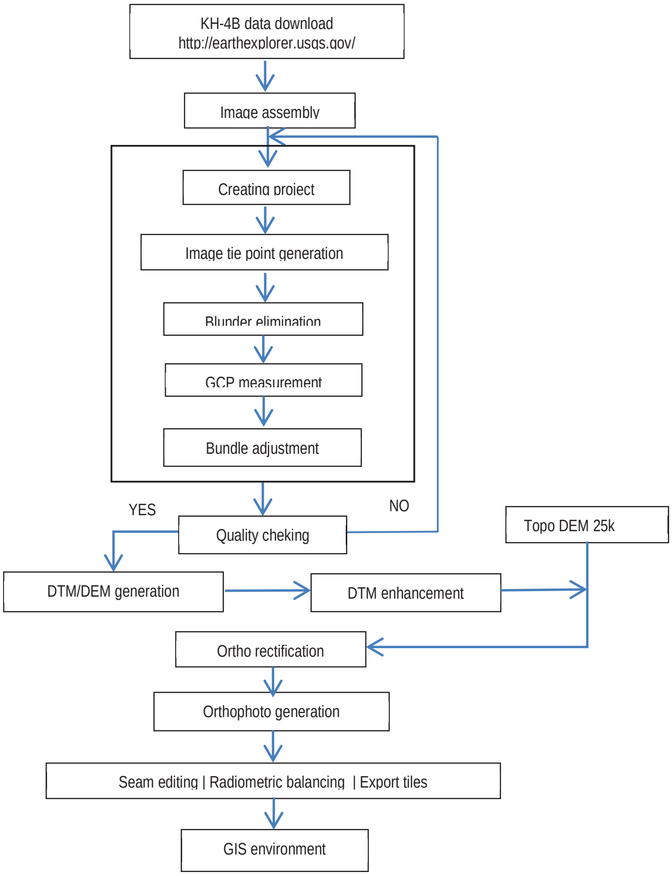

Fig. 2. The photogrammetric workflow for CORONA KH-4B orthophoto production in Iron Gates area.

The first step was the reconstruction of the image geometry in order to solve the orientation problems, according to the available metadata (Table 1)**.** It is known [16] that the geometry of CORONA KH-4B satellite image frame is not the same with a common aerial photo frame, because the twin photographic cameras on the satellite obtained a pair of images, one forward and one backward from the same point, with a rectangular format (16 X 217 km footprint), on negative panchromatic film (grayscale) at 1.8 m spatial resolution (the best value around the principal point). These frames had a 75% common surface, in order to provide the stereoscopic analysis and help the photogrammetric works. Figure 3 is a schematic representation of the frame configuration for the study area. This work was done in image processing software by searching the most reliable common points on frame section and topographic maps at 1:25000 scales. After the four frames reconstruction (two stereo pairs backward-forward images), it was necessary to restore (to build) the interior orientation of the images (calculation of fiducially marks coordinates). The camera model was defined as non-metric in Image Photogrammetry module from Erdas Essential 2015 software provided by Hexagon (Intergraph Romania).

Table 1. CORONA KH-4B metadata used in image geometry reconstruction and interior orientation building process (NRO, 1968).

Image type	Panchromatic (visible) -grayscale (8 bit in digital format)
Focal length	609.602 mm
Flight height	156,000 m
Pixel size	7 µm
Subframe format	43 mm X 252 mm
Image frame format	252.80 mm X 71.0 mm

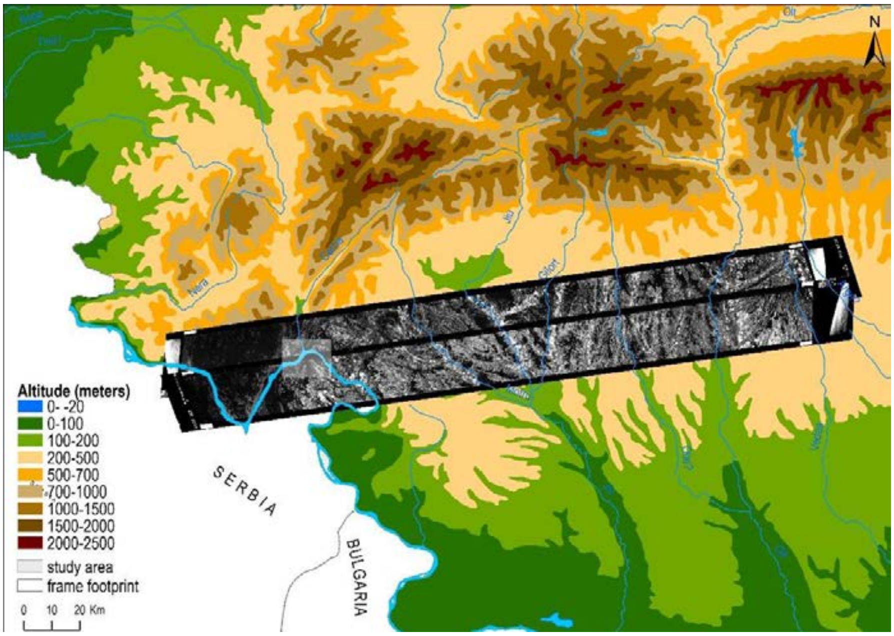

Fig. 3. Satellite image footprints and spatial coverage for CORONA KH-4B processed imagery (August 17, 1968).The map show the particular image frame configuration, the Danube River and the study area.

An aerial triangulation building for the four frames was possible with a set of 30 Ground Control Points (GCP's) produced with the help of actual orthophotos (ANCPI, 2012) and topographic maps at 1:25000 from Romania but also from Serbia, in order to create a block of imagery for the study area. The aerial triangulation points were supplied mainly for the common areas on the satellite frames, following the Danube River channel and existing landmarks. The operation was repeated few times with more GCPs (up to 30 points) and the photogrammetric block was produced.

The DEM was obtained for the photogrammetric block with the help of the network of 30 control points. The result was evaluated only for study area, after the difference between the current DEM and the grid produced from topographic maps. Different areas were modelled with the help of some topographic profile in order to calculate the differences of heights along the new obtained contour lines [17]. For some patches it was necessary to correct some height values by calculating the mean values of the superposing cells, in order to avoid the higher error values at orthocorrection.

Orthocorrection was the last stage of the photogrammetric approach. Using the DEMs, an orthophoto coverage was produced for the common region of the original photo frames. This was evaluated in terms of accuracy with the help of the recent orthophotos (2012), on the Romanian side, after the calculation of the RMSE on the X and Y for 24/26 points. The final data coverage was resized to the study area in order to produce a tile in Stereo 1970 projection (2.0 m resolution), to be coregistered with the recent orthophoto coverage (ANCPI, 0.5 m). Finally, this dataset was enhanced by contrast correction of grayscale signatures (byte image histogram). The panchromatic film (mainly visible) needed a special approach for vegetation signatures (forest-pastures). For the analysis of landscape change it was useful to enhance the brightness levels of the constructions, infrastructures and river water.

3.2. The GIS and mapping approach

After preparing the both datasets (1968 and 2012) we decided to search for an adequate solution for mapping the landscape changes. Because of the high resolution of data in relationship with the size of the change affected objects, in the context of the limited coverage of the study area, a qualitative approach was necessary. This meant that a selection of key features of landscape was converted in vector format, and integrated in a topological model. These were represented by: Danube River channel (2012, after reservoir formation), settlements built-up areas (1968 and 2012), railroad (main line Craiova-Orșova-Timișoara, 1968 and 2012), street network (1968) and the road network (the national roads to Timișoara and Orșova-Moldova Nouă along the Danube River 1968 and 2012).

Landscape change maps were produced in ArcGIS 10 with the help of map editing tools by integrating the orthorectified historical imagery (1968) with the vectors from recent orthophotos (2012) and by superposing vectors on pre-defined available data coverages like the SPOT 5 coverage from Word Imagery (2.5 meters resolution).

4. **Results**

The landscape change analysis returned two types of results. The first group is represented by the historical data coverage, as photogrammetric products derived from CORONA KH-4B frames processing. The second is the set of maps and models showing in a diachronic formula. Both are integrated through the vector data layers selected as key features for landscape change analysis.

After building the photogrammetric block, a Digital Surface Model was produced and resized for the study area, in order to evaluate the height values. The aim was to use the raster data to ortorectify the historical satellite imagery. Its evaluation was done by calculating the simple difference between the DEMs derived from topographic map (1:25000) and the currently elevation data (from CORONA KH-4B dataset). The highest differences are featuring the Danube River channel (banks and gulfs at river junctions) and very limited to some steep slopes or upper catchments with gullies (ex. north-eastern from Orșova towns). An average difference features the largest part of the area around Orșova gulf (it is partly related to the forest cover on higher declivity slopes). The model was also tested through topographic profiles (Fig. 4), and the result is a slight vertical difference of 10-20 m, in some points but a good accuracy in the representation of topography (peaks, saddles, planated surfaces).

The main part of results is the historical orthophoto coverage from August, 17, 1968. This was produced for the common areas between the original image frames at a resolution of 2.0 m (Fig. 5), in order to obtain the geometric configuration of the landscape features before the formation of the Iron Gates Reservoir, upstream the emerging dam. An important task was the evaluation of the geometric quality of the orthophoto, because it is necessary to avoid the possible errors. The evaluation used control points that were reported on the 1968 and 2012 orthophotos for the calculation of the difference between them as positional shifts on X axis and Y axis (Fig. 6). These points were obtained as random samples and followed on ANCPI orthophotos on the Romanian side and on topographic maps on the Serbian side of the Danube River Valley. The 50 selected points on these frames allow the calculation of the RMSE (Root Mean Square Error) as a square root of the difference of position on X and Y values. The data from table 2 show an encouraging value of about 6.0 m for both directions.

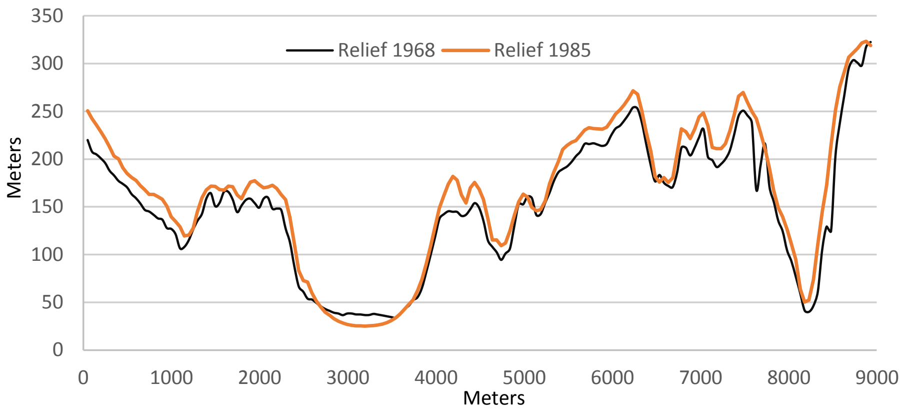

Fig. 4. Topographic profile for Cerna Gulf within the DEMs generated from KH-4Bimages and Topographic Map

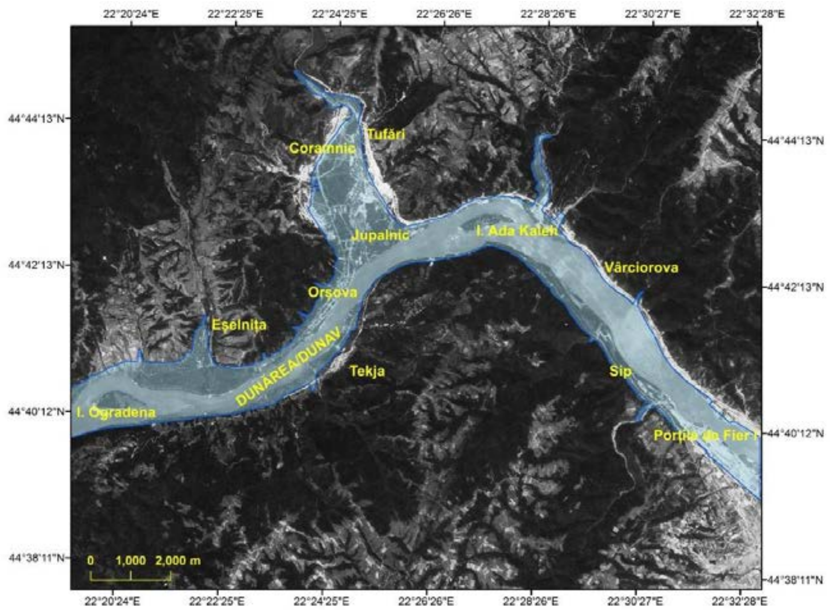

Fig. 5. Sample from the orthophoto coverage from 1968, showing the Ada-Kaleh Island, flooded after the creation of the Iron Gates Reservoir.

Maps of landscape change were the subject of a GIS and cartographic work. The maps were focused on showing in a diachronic perspective the main transformations. For this purpose we produced two versions of maps The first map (Fig. 7) is dedicated on showing the configuration of the Danube River channel in August 1968 in comparison with the present-day configuration. This was obtained by superposing the flooded area on the SPOT 5 image (2.5 m, July 4, 2014) taken from the data coverage available in ArcGIS 10, together with the present-day configuration of the Danube River channel.

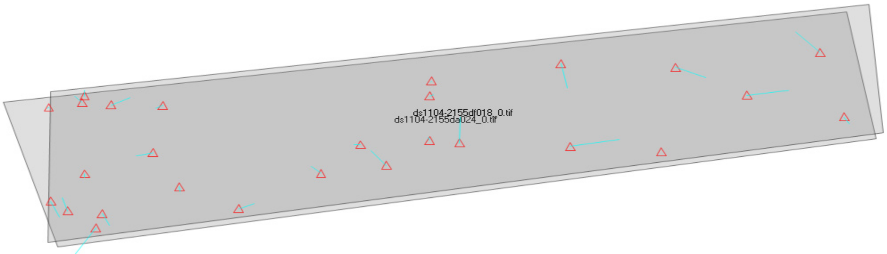

Fig.6. The distribution on GCPs and RMSE vectors

Table 2. Positional accuracies of control points on orthophoto coverage for Iron Gates area

Image ID	*RMSE X*	*RMSE Y*
DS1104-2155DA024	6.550	6.078
DS1104-2155DF018	6.60	6.354

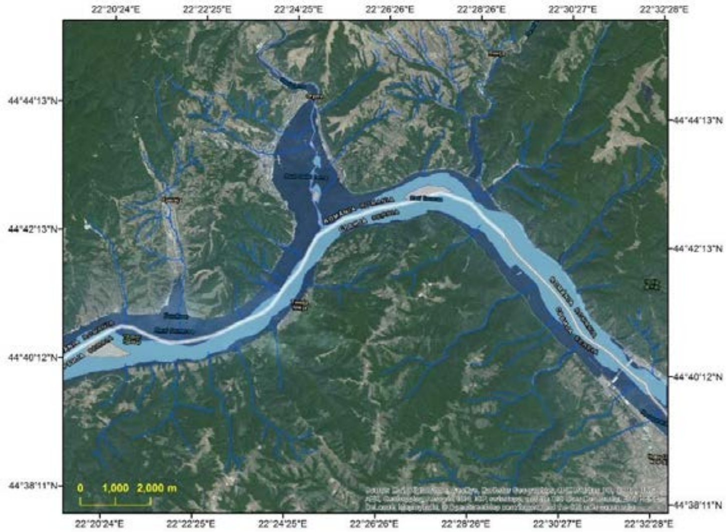

Fig. 7. Map of Danube River channel transformation (1968-2014), based on the vector extraction from orthophoto (1968) and Word Imagery data (2014). The flooding of all junction area at the mouth of the main rivers like Ieşelniţa, Cerna and Bahna can be noticed.

This is combined with basic toponyms in order to show the settlements and especially the flooded islands on the Danube River. The second map (Fig. 8) combines the historical orthophoto (1968) with vector data showing the diachronic configuration of river channel, tributary valley streams, settlements, street and road networks and the railway. This is a better formula to correlate the most affected features with the land cover data that can be interpreted from the grayscale orthophoto on the both sides of the valley, in Romania and Serbia. The map is an objective representation in an accurate geometric formula of landscape changes during a period of more than four decades.

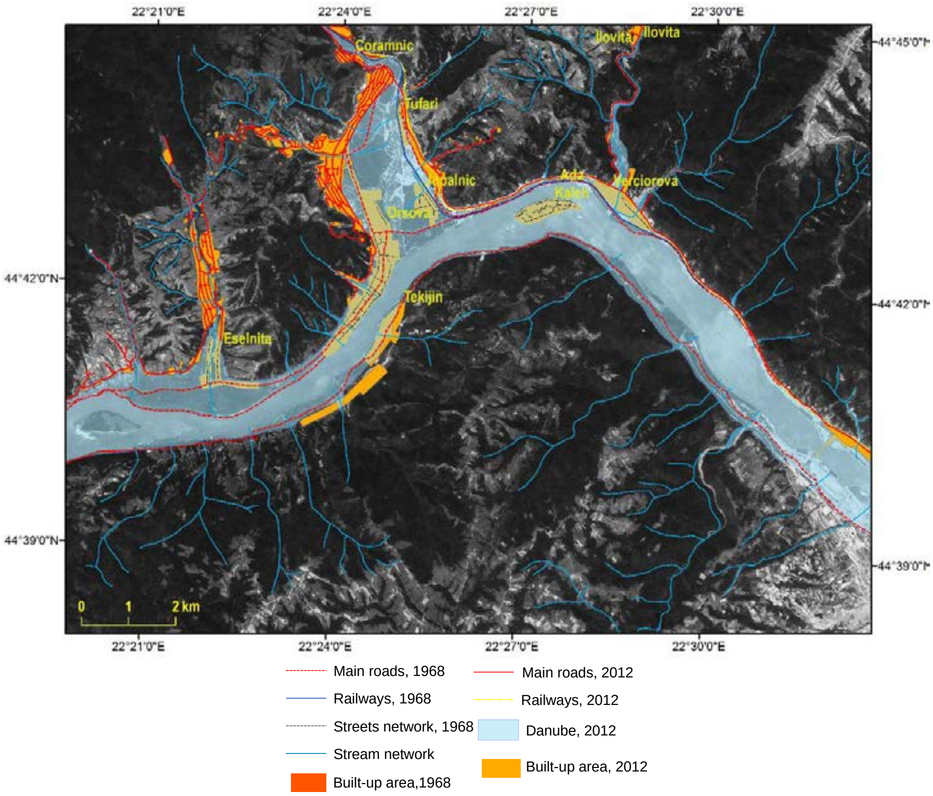

Fig. 8. Map of landscape change in Ieșelnița-Orșova-Gura Văii/Porțile de Fier (Iron Gates) area along Danube River

5. Discussion

Although the analysis of landscape change did not returned the change detection statistics, but the maps can easily explain the exact changes of the environmental features.

For the first part of the study, there are some limitations in image processing, related to some gaps in metadata like for example the data necessary for lens deformation of imagery. The second is the limited volume of GCPs, because they were produced only from orthophotos and topographic maps and not by GPS survey. Although the spectral resolution of the panchromatic imagery (mainly visible spectrum) was limited, it was easy to discriminate between land cover from settlements, road, railroad and engineering works. A contrast uniformisation within the historical orthophoto was used in order to prepare an enhanced image for interpretation. Another aspect is the temporal resolution of the imagery. The available CORONA KH-4B image dates from August 1968, when the formation of the reservoir of Iron Gates already started. The works around the dam were also developing as well as the rebuilding of Orșova town to new site. The main railway and the road were also moving up slope. For this reason, the historical ortophoto is useful but it cannot provide all the landscape features in their configuration before the hydrotechnical works (especially the land cover). For this reason it might be useful to integrate in the analysis older imagery, from 1940s, like for example the archive aerial photos from United Kingdom Royal Air Force (http://ncap.org.uk).

First, the main change was along the Danube River Channel, where large floodplain sectors with wetlands and marshes disappeared together with extended arable land and pastures (the entire flooded surface for the Danube River Defile was of about 10,000 hectares [18]. Orșova, Ieșelnița and Bahna junctions transformed after the total flooding, while on the Serbian side the changes were more or less local after the flooding of smaller alluvial fans to the mouth of forested stream catchments.

The second change features the settlement network, mainly on the Romanian side of the Danube Valley (about 30,000 inhabitants moved along the Danube River Defile). Orșova town built-up area moved with 3 km to the northwest from the low terraces (6-8 m, 10-20 m relative altitudes) and the floodplain at Cerna River junction to the higher terraces but mainly to the mountain slopes affected by landslides [19]. The town became more compact by the grouping of the former separate districts (Tufări, Jupalnic, and Coramnic with the new town built-up area). The orthophoto from 1968 show in the same time the old Orșova (8,106 inhabitants in 1966) and the emerging new Orșova town (11,832 inhabitants in 1972, 10,441 in 2011), because the works already started with the formation of the reservoir in 1965.The new town of Orșova has a totally new urban physiognomy, following the contour lines and the stream network, and was designed as a typical socialist industrial town (shipyard, port, textile factories, mining, food industry and some tourist developments).

Together with the old Orșova moved other villages or part of built-up areas like Ieșelnița (Romanian side) and Tekija (Serbian side), but the main change features the flooded villages like Vârciorova at Bahna River junction and especially Ada-Kaleh, with the entire island on Danube River channel. This meant the abandonment of the old Turkish village and the disappearance of the Vauban fortress, moved on Șimian Island, downstream the dam (in a poor condition today).

Transportation network also changed dramatically, after the flooding of the road on Romanian and Serbian sides as well as of the railway on Romanian side. There were built viaducts (22 on railroad and 36 on the road) and tunnels (7 on railway, 2 on the road) on upper slopes (32 m higher than the older position of the railroad) in order to re-create the new transportation axis (electrified railway from 1970, DN 6-E 70 main highway).

KH-4B declassified images offer a huge potential by their time series coverage, superposing on stages with an intensive transformation of the landscape. They pass beyond the political and administrative restrictions for socialist period in Central and Eastern Europe. They also provide an objective basis for assessing environmental changes, and creates the premise for initiating projects to mitigate natural hazards where possible. The main limitation is related to the DEM generation, whose vertical accuracy is not enough for all detailed analysis. This that can be improved by increasing the number of ground control points

6. **Conclusion**

CORONA KH-4B imagery from DECLASS-1 archive datasets might be a good alternative for landscape change analysis at detailed scales. Their higher resolution and spatial coverage focused on Central and Eastern Europe, together with the former USSR, to the end of the 1960s and the beginning of 1970s, enhance their role of visual historical archives of the intensive industrialisation and centralized economic growth process. For the environmental issues it can be useful to understand the dynamics of ecosystems in the context of their extensive replacements by industrial development.

From the technical point of view, the integration of CORONA KH-4B in the landscape change analysis can replace a long and time consuming photogrammetric process with a large number of digitized normal aerial photos. These images are not every time available with metadata and for sensitive area (ex. along borders or on towns) and need a special approach.

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